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A deterministic dynamic model of optimizing university training structure

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Abstract: The article explores the problem of optimising university training structure to increase focus on the labour market. The proposed solution is constructed using a deterministic approach in which the following vectors are formed: the phase vector, whose coordinates are the values of the parameters describing the training process in higher education institutions at a certain fixed point in time; the controlling action vector (control vector) that allows influencing (by means of funding, the school-leaving exam score required for admission and other parameters) the structure, volume and quality of university training on various degree courses (educational programs), as well as the corresponding deterministic restrictions. The construction of the optimisation model is realised in two stages. At the first stage, a discrete dynamic model is formed that describes the influence of the control vector on the parameters of the system parameters phase vector. At the second stage, restrictions are formed on the parameters of the mathematical model that take into account the labour market demand for university graduates, and the quality criteria (functionals) that allow evaluating the process under consideration at a set final point in time.

Keywords: Deterministic approach, optimization, higher education, labour market

1. INTRODUCTION

Economic research currently has to address a number of major issues: economic relevance of the educational process structure, correlation between the demand and supply on the labour market and the market of educational services, and optimisation of the higher educational institutions' activities aimed at attracting school leavers to degree courses, fields and specialities that are essential for economic development.

In addition, the following problems still remain unresolved: the imbalance in the structure of degree courses for various specialities (fields) at different levels of education (higher-secondary), the educational institutions' and applicants' insufficient consideration of the national economy real needs, which leads to the reduction in the educational system effectiveness (Fig. 1).

At the same time, the share of university graduates increases every year, while the share of secondary and basic vocational education institutions graduates decreases. In 1990, the number of professionals with secondary and basic professional (vocational) education was 4.8 times higher than the number of university graduates; in 2015 there were 1.6 times more professionals with university degrees than specialists with a secondary and basic vocational qualification.

Another problem of Russian education is the contradiction between the study paths individuals prefer to choose and the needs of the real economy.

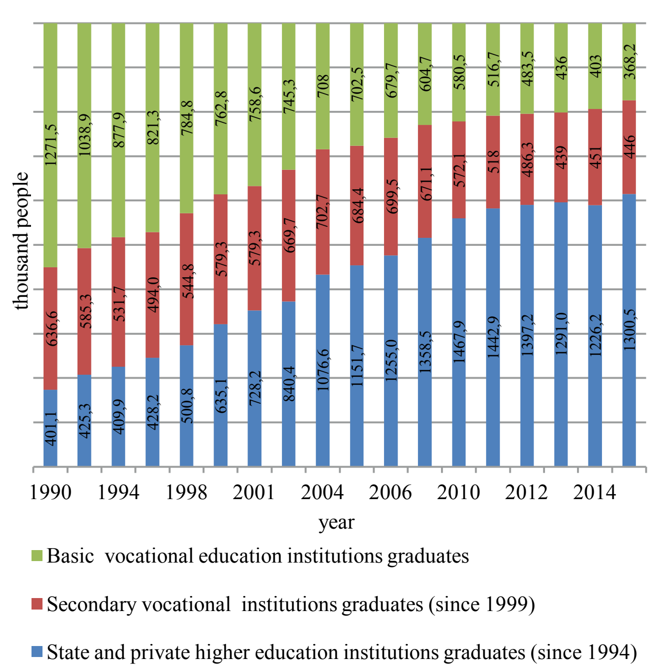

Fig. 1. The structure of training by education levels in Russia

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This trend is perfectly illustrated by the regular statements made by the government authorities and publications in the press about the "overproduction" of lawyers, economists and managers and the acute shortage of workers and specialists with secondary vocational, especially technical, qualifications. By 2013, the number of graduates in social sciences and humanities accounted for 73% of the total number of university graduates, those in economics and management – 33% (Fig. 2).

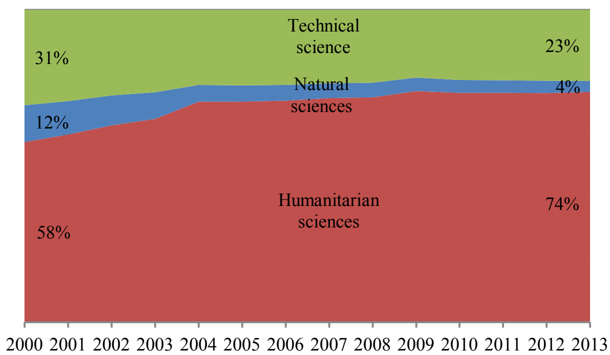

Fig. 2. Structure of degree courses in the higher educational system

There are several studies that focus on predicting the relevant fields of training (Gurban et al., 2016; Razumovskaia, et al., 2016).

Besides, there is a weak correlation between the qualification that graduates receive and their job. As of 2013, 70% of university graduates' jobs were connected with the obtained qualification; this figure is even lower for those with secondary or basic vocational education – about 55%.

The problems identified above emphasise the need for stronger orientation of the university training structure towards the labour market needs.

Therefore, the authors set the objective of constructing an optimisation model of the bachelor's, specialist and master's degree programmes oriented towards the labour market needs, which will be realised using the deterministic approach (Shorikov, 2005; Lotov, 1984; Propoy, 1973; Ter-Krikorov, 1977).

Indeed, existing approaches to solving similar problems of education management are based mainly on static models. These models use the stochastic modeling apparatus, which requires knowledge of the probabilistic characteristics of the main model parameters and special conditions for the implementation of the considered process. It is necessary to highlight, that very stringent conditions are required for the use of the stochastic modeling apparatus, which in practice, usually, are not feasible beforehand.

Therefore, in our paper we use a deterministic approach that takes into account that the majority of the parameters of the considered processes are deterministic and that geometric limitations on a priori indeterminate parameters are known from the experiment - the sets of their possible values. In cases where, for some indefinite parameters their probabilistic characteristics are known, according to the "three sigma" rule, it is possible to form geometric constraints on their possible values and use a deterministic approach.

Hence it can be concluded that the deterministic approach and the corresponding methods of the mathematical theory of control processes have broader applications to the decision-making tasks.

2. DETERMINING THE PHASE VECTOR AND THE CONTROL VECTOR

To determine the parameters of the model for the training process under consideration the authors had to do the following:

1. Determine the criteria for the quality of university training.

2. Define the criteria for the labour market demand for new professionals.

3. Form the phase vector of the process ("the object state vector"), construct its transformation matrix.

4. Form the control vector of the process, construct its transformation matrix.

Table 1. List of indicators to form the phase vector and control vector matrices

PHASE VECTOR	
Demand for graduates (types of degree courses and specialities)	
1	The number of full-time bachelor's degree graduates
2	Share of graduates who found employment within a year after graduation in the total number of graduates of the higher education institution
Demand for graduates (degree levels)	
3	Average score in the graduation certificates by field (institute)
4	Number of students per one teaching staff member
	Number of full-time undergraduates on bachelor's and specialist degree courses
	Number of full-time teaching staff positions
5	Share of students actively involved in educational and research activities
	Number of awards (medals, certificates, etc.) received in exhibitions and scientific research contests
	Number of scientific publications: * total number of publications co-authored by students; * number of students' independent publications, not co-authored by any university staff members
	Number of intellectual property copyright registration certificates that include students
CONTROLLING ACTION VECTOR	
6	Average USE (Unified State Exam, Russian school-leaving exam) score of undergraduates studying on bachelor's and specialist degree courses
7	Share of state-financed places
8	Number of scholarship awardees

Since the study uses a deterministic approach that requires setting unambiguous targets, the authors formulated the following four objectives:

1) minimising the number of unemployed graduates;

2) minimising the discrepancy between the number of successful university applicants and the number of graduates;

3) maximising the number of students' awards (certificates, diplomas, medals, etc.).

The next section describes the mathematical formalisation of the optimisation model of the structure of bachelor's, specialist and master's degree training with the orientation to the labour market needs.

Table 1 shows the indicators that form the phase vector and the control vector. The authors determined that the phase vector (the object state vector) describes two types of parameters: the need for university graduates by field and by education level.

3. A DYNAMIC MODEL FOR PROGRAM CONTROL OF THE TRAINING STRUCTURE

On an integer time interval $\overline{0,T} = \{0,1,...,T\}.$ $(T \in N)$; hereinafter, N is the set of all natural numbers), a model of the dynamics of the process of program control of university training structure (PCUTS) is formed as a system of linear discrete recurrence equations:

$$x(t+1) = A(t)x(t) + B(t)u(T), \\ x(0) = X_0, \quad t \in \overline{0,T-1} \tag{1}$$

where $x(t) = \{x_1(t), x_2(t),..., x_n(t)\} \in R^n$ – is the phase vector of the system (n ∈ N);

$u(t) = \{u_1(t), u_2(t),..., u_p(t)\} \in R^p$ – is the control vector (p ∈ N) (hereinafter, R^k – is k- dimensional vector (Euclidean) space of column vectors, even if they are written into a row to save space.

To determine the main parameters characterising the dynamics of the process under consideration, i.e. to form the elements of matrices A(t) and B(t), it is necessary to describe the information capabilities of the subject of control *P* in the process of program control (Shorikov, 2005; Shorikov, 1997) by the dynamic system.

It is assumed that in the course of PCUTS process and fixed natural number s>>T>0 implementation, at every moment in time $t \in \overline{1,T}$ the control subject has the following information capabilities corresponding to the realisations of the system phase vector, to the controlling action and to the risk vector on the integer time interval $\overline{-s,t}$, preceding the control process under consideration:

1) the history of the system phase vector realisation is known

$$x_t(\cdot) = (x_1(\cdot)_t, x_2(\cdot)_t, ..., x_7(\cdot)_t = \\ \{(x_1(\tau), x_2(\tau), ..., x_7(\tau))\}_{\tau \in \overline{-s,t}} = \{x(\tau)\}_{\tau \in \overline{-s,t}};$$

2) the history of the system controlling action realisation is known

$$u_t(\cdot) = (u_1(\cdot)_t, u_2(\cdot)_t, u_3(\cdot)_t, u_4(\cdot)_t) = \\ \{(u_1(\tau), u_2(\tau), u_3(\tau), x_4(\tau))\}_{\tau \in \overline{-s,t-1}} = \{u(\tau)\}_{\tau \in \overline{-s,t-1}}.$$

Since the variables of the phase vector and the control vector are independent on each other (they cannot be expressed by means of one another), to construct the system of recurrence equations (1), i.e. to form matrices *A(t)* and *B(t)*, the tools of regression-correlation analysis or an algorithm based on solving systems of linear algebraic equations that use the data of the process history can be applied. The database of the activities of Russian universities was created for this purpose.

Then, based on the available data, the ***problem of posteriori identification*** (Shorikov, 2005; Shorikov, 1997) of all the basic elements of the discrete dynamic system (1) was solved, i.e. the elements of matrices *A(t)* and *B(t)* were formed.

As a result of solving this problem, matrices *A(t)* and *B(t)* have a specific form, and system (1) describes the dynamics of the PCUTS process under consideration.

Then, based on the available conditions of the dynamic system parameters realisation (1), the following restrictions are formed, which determine the areas of their admissible values:

$$\forall t \in \overline{0,T} \ ... \ x(t) \in X_1(t) \subset R^n,$$

$$X_1(t) = \{x(t) : x(t) = \{x_1(t), x_2(t),..., x_n(t) \in R^n, \\ \forall i \in \overline{1,n}, x_i(t) \in \Delta x_i(t)\}, \tag{2}$$

where $\Delta x_i(t) \subset R^1$ is a closed numerical interval; that is, at every moment in time $t \in \overline{0,T}$, the values of the phase vector of the dynamic system under examination are limited by the corresponding polyhedron (parallelepiped) in space R^n;

$$\forall t \in \overline{0,T-1} \ ... \ u(t) \in U_1(t) \subset R^p,$$

$$U_1(t) = \{u(t): \quad u(t) \in \{u^{(1)}(t), u^{(2)}(t),..., u^{(N_t)}(t)\},$$

$$U_1(t) = \forall t \in \overline{0,N}, u^{(i)}(t) = \{u_2^{(i)}(t), u_2^{(i)}(t),..., u_p^{(i)}(t)\} \\ \in U*(t)\},$$

$$U*(t) = \{u(t): u(t) = \{u_1(t), u_2(t),..., u_p(t) \in R^p, \\ \forall i \in \overline{1,p}, u_i(t) \in \Delta u_i(t)\}, \tag{3}$$

where $\Delta u_i(t) \subset R^1$ is a finite set of numbers; $U_1(t)$, for each $t \in \overline{0,T-1}$, there is a finite set of vectors – different values of ***control intensity*** in the PCUTS process, namely, a finite set that consists of $(N_t \in N)$ vectors in R^p.

The subject *(P)* of the PCUTS process is supposed to know the equation (1) and restrictions (2), (3).

The PCUTS process under consideration is assessed by the value of vector functional (quality criterion) $\Phi=(\Phi_1, \Phi_2, \ldots, \Phi_r)$ (where $\Delta i \in \overline{1,r}, \Phi_i: \quad R^n \to R^1$ is a scalar-valued functional) determined on possible realisations of the final state of the trajectory $x(T) = \bar{x}(T;\overline{0T}, x(0), u(\cdot)) \in R^n$ of the system (1) on the time interval $\overline{0,T}$, generated by set (x(0),u(·)), satisfying the following conditions in accordance with restrictions (1) – (3)

$$\forall t \in \overline{0,T}:$$
$$x(t) = \bar{x}(t;\overline{oT}, x(0), u(\cdot), v(\cdot)) \subset X_1(t);$$
$$u(\cdot) = \{u(t)\}_{t\in\overline{o,T-1}}, \quad \forall t \in \overline{0,T-1}: u(t) \in U_1(t)$$

and the values of this vector functional, in accordance with the scalarisation method for vector functional, are calculated by means of the following formulae:

$$\Phi(\bar{x}(T;\overline{0T}, x(0), u(\cdot))) = \Phi(x(T)) = \sum_{i=1}^{r} \lambda_i \Phi_i(x(T)) \,, \quad (4)$$

$$\forall_i \in \overline{1,r}: \gamma_i :\geq 0, \sum_{i=1}^{r} \lambda_i = 1 \,. \quad (5)$$

Then, for the system (1) – (5), the objective of the *program* PCUTS process from the point of view of the control subject *P* can be formulated as follows: on a set time interval $\overline{0,T}$, the control subject P is required to form such program control $u^{(e)}(\cdot) = \{u^{(e)}(t)\}_{t\in\overline{0,T-1}}$ (for all $t \in \overline{0,T-1}: u(t) \in U_1(t)$), that the value of functional Φ is minimum (maximum), defined on the corresponding realisation of trajectory $x^{(e)}(T) = \bar{x}(T;\overline{0T}, x(0), u^{(e)}(\cdot)) \in R^n$ of system (1).

The general scheme for achieving the objective of optimisation (PCUTS) for a given point in time (T) involves completing three main tasks.

1. Identifying the dynamics of the process under consideration, i.e. forming the parameters of a discrete dynamic system of type (1). To identify the dynamics of the system, an iterative algorithm is proposed, which combines the procedure for solving multidimensional systems of algebraic equations and the mean square interpolation of the source data.

2. Calculating the value of the functional (4) for fixed program control.

3. Forming optimal program control $u^{(e)} = \{u^{(e)}(t)\}_{t\in\overline{0,T-1}}$ for the optimisation task under consideration (PCUTS).

4. CONCLUSION

The modeled parameters for optimising the structure of university training should be the target indicators for regional development and reflect the processes involved in the modernisation of the higher professional education system (transition to a two-level education system) and the labour market demand for qualified personnel.

The parameters of the dynamic system (1), (2), formed in accordance with the requirements to optimise the structure of training, which determine vector *x(t)*, are: the number of students studying on higher professional education degree courses (specialities), the number of unemployed university graduates (by field/speciality).

The main parameters for managing the structure of university training (the parameters of vector *u(t)*) are the average wage (by field) in the region, the number of state-funded places, and the average USE score required for university admission (by field and speciality).

In conclusion, it should be noted that the construction of the optimisation model for the examined process is realised within the framework of a deterministic approach based on the formation of a system that describes the dynamics of the process and contains a phase vector and a control vector. The construction of the mathematical model for the process as a whole is carried out in two stages.

At the first stage, the influence of the control vector parameters on the phase vector parameters is determined, i.e. the equations describing the dynamics of the process are derived. At the second stage, restrictions on the control vector (management resource) are formed, taking into account the labour market demand for university graduates, and quality criteria (functionals) are defined that allow evaluating the graduates' quantitative and qualitative characteristics.

The proposed model allows to estimate and calculate an optimized scenario of the university's output taking into account the regional market demand. The main result of our model consists in the reduction of the total number of unemployed graduates of the university and in improving the quality of students training.

As a part of the further work on model development it is proposed to carry out a model optimisation of the university's output scenarios taking into account the labour market demand for enlarged graduates' specialities.

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